Exercise 5 (Individual, 36 Points Total) **Leigh Tesfatsion**
DATE: Thursday, March 26, 5:30pm **EE/Econ 458, Spring 2009**

EXERCISE 5:
Economic Dispatch of Electric Power

References for Exercise 5: EE/Econ 458 Syllabus Section III

[1] ** L. Tesfatsion, *Optimization Basics for Electric Power Markets*, ON-LINE
www.econ.iastate.edu/classes/econ458/tesfatsion/OptimizationBasics.LT458.pdf

[2] ** D. Kirschen, *Optimization Tools for Economic Dispatch Calculation*, ON-LINE
.../econ458/tesfatsion/EconomicDispatchIntroToOptimization.DKirschen2004.LTEdits.pdf

[3] ** G. Sheble and J. McCalley, *Cost Function Determination and Economic Dispatch Calculation: Worked Examples*, ON-LINE
.../econ458/tesfatsion/EconDispatchCalculation.GShebleJMcCalley1999.LTEdits.pdf

General Exercise Instructions:

(a) This exercise consists of FOUR QUESTIONS, some with several parts.

(b) Be sure to show all your work so that partial credit can be given for answers even if some type of error occurs along the way.

(c) Read each question part carefully before you begin your answer.

(d) Define terms and concepts clearly and carefully.

(e) Carefully label all graphs. This includes labels for axis variables as well as labels that carefully identify what is being graphed.

(f) It is recommended that you make an extra copy of your answer packet for use in class discussion on the due date. Individuals will be called upon to report their findings.

(i) Recall that late assignments cannot be accepted – no exceptions! Make sure your exercise is turned in to the instructor or TA at the *beginning* of class on the due date. Do not send your exercise in via email or place it in a department mailbox as these sites might not be checked in time.

QUESTION 1 (25 Points Total)

A system consists of two generators, G1 and G2, supplying electric power to service a fixed demand (load) P_D in a particular hour H. The short-run cost curves (\$/hr) for G1 and G2 in hour H are as indicated below:

$$SRC_1(P_{G1}) = 0.02 \cdot [P_{G1}]^2 + 2.0 \cdot P_{G1} + 80 \ ; \quad (1)$$

$$SRC_2(P_{G2}) = 0.03 \cdot [P_{G2}]^2 + 1.0 \cdot P_{G2} + 200 \ . \quad (2)$$

The operating capacity limits (in MWs) for G1 and G2 during hour H are as follows:

$$10 \ MW \ \leq \ P_{G1} \leq \ 100 \ MW \ ; \quad (3)$$

$$30 \ MW \ \leq \ P_{G2} \ \leq \ 100 \ MW \ . \quad (4)$$

The system is managed by a market operator tasked with solving an economic dispatch problem for hour H. Assume for simplicity, below, that G1 and G2 are connected through a loss-less transmission grid with infinite capacity (no transmission congestion).

Part A: (10 Points Total) Suppose the total fixed demand for this system in hour H is $P_D = 140$ MW.

- (1) (1 Point) Express in analytical form the economic dispatch problem for this system in hour H. Explain carefully the economic and/or physical meaning of the different aspects of this economic dispatch problem.

- (2) (1 Point) Carefully write down an appropriate Lagrangian function for this economic dispatch problem for hour H.

- (3) (3 Points) Using the Lagrangian method, determine the hour-H economic dispatch solution levels P^*_{G1} and P^*_{G2} (MWs) for G1 and G2 along with the economic dispatch solution λ^* (\$/MWh) for the Lagrange multiplier λ.

- (4) (1 Point) Explain carefully why λ^* satisfies the definition of a *locational marginal price* for this economic dispatch problem.

- (5) (2 Points) Suppose G1 and G2 receive λ^* (\$/MWh) for each MW they sell in hour H. Calculate each generator's sales revenue, short-run cost, short-run variable cost, and short-run profit at its operating point, i.e., at P^*_{G1} for G1 and at P^*_{G2} for G2, where short-run profit for each generator is defined as its sales revenue minus its short-run cost.

- (2) (2 Points) Using your findings from (5), do G1 and G2 each make a positive short-run profit in hour H? If not, does this mean that one or both generators should definitely shut down in hour H instead of offering electric power for sale through economic dispatch? Explain carefully.

Part B: (13 Points Total)

- (1) (10 Points) Repeat Part A for the case in which the total fixed demand for hour H is instead given by $P_D = 190$ MW.
- (2) (1/2 Point) How does the increase in total fixed demand from 140MW (in Part A) to 190MW (in Part B) affect *total system operating cost in hour H*, defined as the total payments made to G1 and G1 to service total fixed demand in hour H?
- (3) (1/2 Point) How has this increase in total fixed demand in hour H affected *average system operating cost in hour H*, defined as total system operating cost in hour H divided by the total fixed demand serviced in hour H?
- (4) (2 Points) Explain carefully the reason(s) for the effects on total and average system operating cost in hour H determined in parts (2) and (3).

Part C: (2 Points) Suppose that for this system, under a certain economically dispatched scenario (a scenario different than in Parts A and B), it is found that servicing an additional 1 MW of fixed demand costs an additional \$5.68/hr. Determine the economic dispatch solution levels P^*_{G1} and P^*_{G2} for G1 and G2 under this scenario.

QUESTION 2 (3 Points)

Carry out Problem 4.6 on page 103 of the Kirschen/Strbac (K/S) textbook, as follows.

An **answer** for Problem 4.6 is provided in the K/S Appendix (p. 270). **Your** task is to carefully *derive* this answer to establish its correctness (or to carefully show why you believe a provided answer is not correct if that is what you conclude).

QUESTION 3 (4 Points)

Carry out Problem 4.7 on page 103 of the Kirschen/Strbac (K/S) textbook, as follows.

An **answer** for Problem 4.7 is provided in the K/S Appendix (p. 270). **Your** task is to carefully *derive* this answer to establish its correctness (or to carefully show why you believe a provided answer is not correct if that is what you conclude).

QUESTION 4 (4 Points)

Carry out Problem 4.8 on page 103 of the Kirschen/Strbac (K/S) textbook, as follows.

An **answer** for Problem 4.8 is provided in the K/S Appendix (p. 270). **Your** task is to carefully *derive* this answer to establish its correctness (or to carefully show why you believe a provided answer is not correct if that is what you conclude).